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DRAWDOWN CONTOUR MAPS THAT ARE CAUSED BY WELL PUMPING IN UNCONFINED AQUIFER UNDER ISLAMIC UNIVERSITY OF INDONESIA AND IN VICINITY AREA WITH HYPOTHETICAL CASE

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ABSTRACT

Investigation of groundwater for a region is required to know water table condition in the aquifer below the ground surface. Penetrating the well in aquifer and pumping it water caused the groundwater surface go down. That condition call water table drawdown. Drawdown contour map in the aquifer can be developed using the groundwater flow theory. The results are drawdown contour maps in influence area as the circular and rectangular shape. Maximum drawdown is occurred in area with one well and minimum drawdown in area with four wells. Differences of drawdown contour map pattern generally are caused by shape of influence area.

KEYWORDS: Groundwater, Unconfined Aquifer, Drawdown, Map

INTRODUCTION

Islamic University of Indonesia (IUI) covered land about 30 hectares in Jalan Kaliurang Yogyakarta, Indonesia (Figure 1 and 2). Present of IUI in this area lead to high housing growth in this zone in the two decades and more. This situation gives impact on use of groundwater on a large-scale.

Figure 1: Yogyakarta Special Provence, Indonesia (Accessed from https://www.google.com/search?q=java+island (June, 28, 2015)

The people in this area have been taking the water from family well penetrated to the aquifer under ground surface by a pump in a long time. In a whole year the people rare experience lack of water. Withdrawal the water from unconfined

aquifer on a large-scale will cause an unnaturally rapid change in a groundwater system. The result is some major perturbations of the water table, Buddemeier (accessed from http://www.kgs. ku.edu/HighPlains/atlas/apdrdwn.htm, June, 30, 2015). The shortage of the water for the people in the future perhaps occurred, but when that condition will turn up, we don't know. According to water table drawdown some researchers has studied of this topic. Mudoch and Franco (1994) extend the ISF method to the analysis of constant drawdown source. In accordance with groundwater and aquifer drawdown prediction study used the MODFLOW mathematical model, some authors have written the papers.

Figure 2: IUI Campus Area (Accessed from Google Earth June, 28, 2015)

The structural effects of basin and irrigation on groundwater levels have been examined by Ramireddygari et al. (2000) to study the interaction between rivers, aquifers. Surface water model and the MODFLOW model were combined in this study. Thorley and Callander (2005) have simulated ground water using the MODFLOW model in Christchurch, New Zealand. GIS and numerical modeling was used by Chenini and Mamou (2010) to identify suitable sites for artificial recharge and development of under groundwater resources in Central Tanzania. GIS use is to produce thematic layers and the MODFLOW-2001 code to estimate the effects of recharge on hydrogeological system piezometric behaviors. Purjenaie *at al*., (2012) predict the Sarze Rezvan aquifer drawdown using the MODFLOW mathematical model after to investigate adaptation of the model to the aquifer's natural conditions.

The objective of this study is to develop the constant drawdown map of groundwater level because pumping in unconfined aquifer under Islamic University of Indonesia and around area using finite element procedures. We used hypothetical case by define drawdown influence area of the well inside.

GROUNDWATER FLOW THEORY

Prior by Darcy's law equation (1), the theory of groundwater flow is started with derive the equation based on the law.

$$q = k\frac{d\phi}{ds} \tag{1}$$

In cartesian coordinate system, equation (1) can be perform as,

$$q_x = -k_x \frac{\partial \phi}{\partial x}; q_y = -k_y \frac{\partial \phi}{\partial y}; q_z = -k_z \frac{\partial \phi}{\partial z} \tag{2}$$

Based on flow element in cube form, equation (2) can be derived back to be,

$$k_x \frac{\partial \phi}{\partial x} + k_y \frac{\partial \phi}{\partial y} + k_z \frac{\partial \phi}{\partial z} = 0 \tag{3}$$

(Or)

$$k_x \frac{\partial^2 \phi}{\partial x^2} + k_y \frac{\partial^2 \phi}{\partial y^2} + k_z \frac{\partial^2 \phi}{\partial z^2} = 0 \tag{4}$$

Equation (4) in two dimensional space system is,

$$k_x \frac{\partial^2 \phi}{\partial x^2} + k_y \frac{\partial^2 \phi}{\partial y^2} = 0 \tag{5}$$

Where ϕ, k_x, and k_y are potential function, permeability coefficient in x direction and y direction respectively. If into the aquifer are penetrated wells for source and or sink, so that the equation (5) can be rearranged to be,

$$k_x \frac{\partial^2 \phi}{\partial x^2} + k_y \frac{\partial^2 \phi}{\partial y^2} + Q = 0 \tag{6}$$

Where Q is source and or sink. Q is plus sign for recharge and minus sign for discharge.

Solution of equation (6) by finite element is a main analysis to obtain the map of drawdown contour in the site. Equation (6) due to pumping with constant discharge is a steady state problem.

DATA AND METHOD

Investigation of groundwater level has been carried out at coordinate about (110.2^0 longitude ; -7.23^0 latitude) by soil mechanics laboratory of Civil Engineering Department (CED) of IUI. The result of the investigation was the direction of groundwater flow is north-south direction and the groundwater level on dry season about 20 m below the ground surface and in rainy season about 9 m. The Laboratory also predicted that the soil permeability coefficient have average value about 1.25 cm/minute. This value is equal to 75 m/day. From some of family well in this area are obtained (see Figure 1) that the groundwater level on dry season also about 20 m below the ground surface and in rainy season about 9 m. So that it is known that the peoples are residence here do not feel less water in whole year. With this condition generally the water level condition in this area is range between 9 m to 20 m below the ground surface every year. Those groundwater levels above are utilized as a basis to determined boundary condition for the analysis. For the analysis, impermeable soil layer or rock layer is assumed at 100 m depth below ground surface. Therefore the depth of aquifer or water table is ranges from 100 – 20 = +80 m on dry season to 100-9 = +91 m on rainy season. Based on these depths, it can be found that the value of potential function, ϕ = 80 m on dry season and ϕ = 91 m on rainy season.

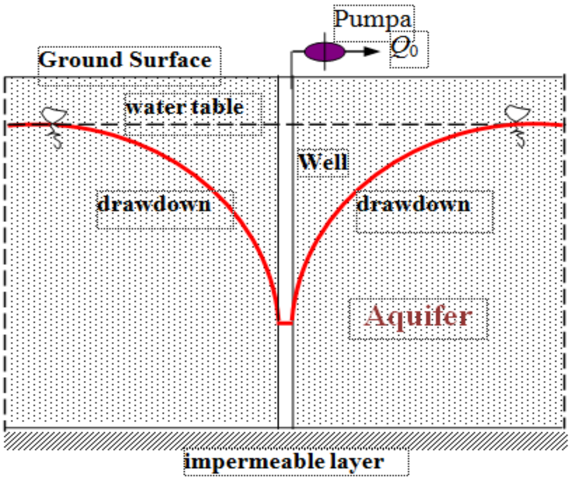

Figure 3: Well in Aquifer

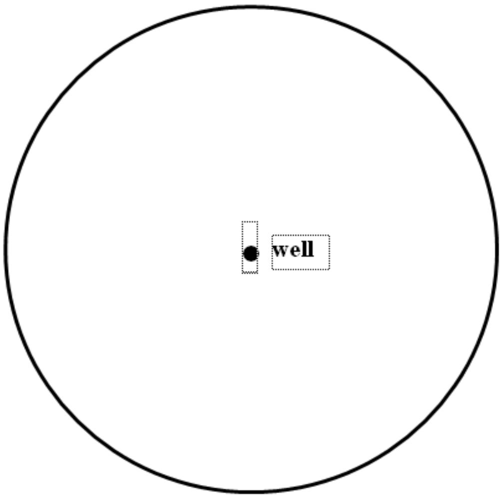

Figure 4: Drawdown Influence (Black Color Bullet is Well)

If into the aquifer is penetrated a well at the particular point and the water in the well is pumped for certain purpose, consequently the drawdown of the water table will be grown (Figure 3).

The influence of water pumping from the well (drawdown) is assumed 1.5 km to 2.0 km from the well. Hence the shape of that influence is also supposed as a circle with center is the well (Figure 4). This circle is called as a study area. The border line of the area is considered as a border of boundary condition. Because edge of the circle far enough from the well pumped so that a constant head is maintained.

It will be studied four pattern of placing of the well in the area: *i*) area with one well (Figure 5a), *ii*) area with two well (Figure 5b), *iii*) area with three well (Figure 5c), and *iv*) area with four well (Figure 5d).

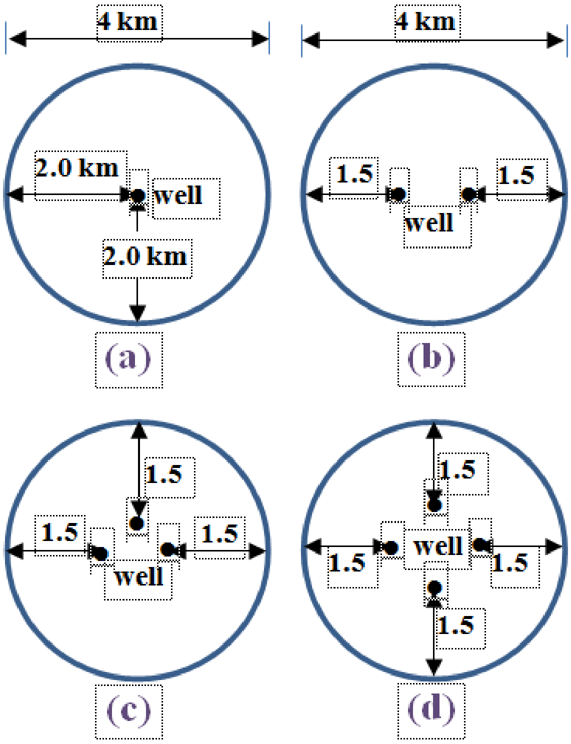

Figure 5: Pattern of Placing Well in Circle Area

Additionally, it is studied the influence area of drawdown with rectangular outline (Figure 6). The dimensions of rectangular are long 5 km (north-south direction) and width 3 km (east-west direction). The right and left side of area are assumed blocked by impermeable soil layer vertical due to the soil surface, see (Figure 6) (Segerlind, 1984).Therefore the drawdown process will be dominated by groundwater moving in north-south direction in aquifer according to the well. There are four pattern of well placing in rectangular border line that used in analysis.

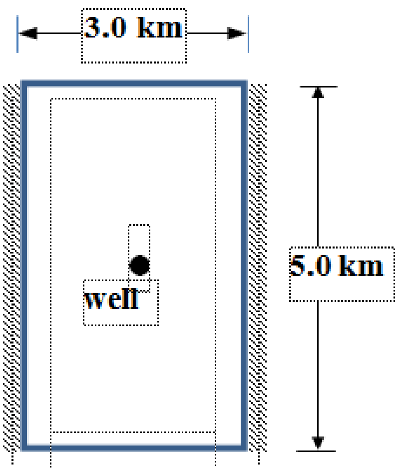

Figure 6: Rectangular for Drawdown Influence

a) Rectangular with one well Figure 7a, b) rectangular with two well Figure 7b, c) rectangular with three well Figure 7c, and d) rectangular with four well Figure 7d.

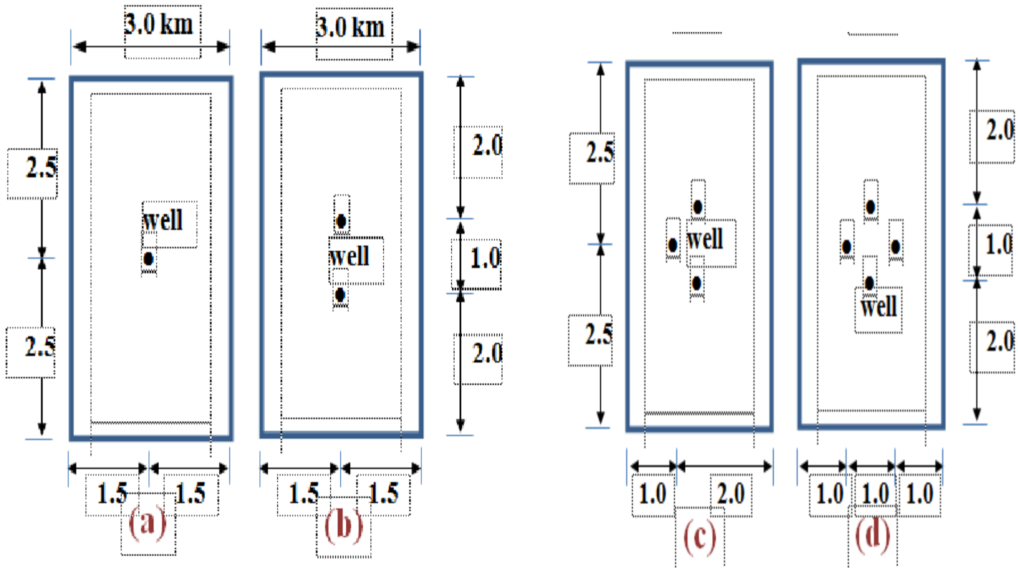

Figure 7: Pattern of Placing Well in Rectangular Area

Center of studies area (circular and rectangular) is the university zone (IUI), see Figure 2.

COMPUTATION

The boundary condition for computation is value of potential function (ϕ) on border line of area. Drawdown calculated for dry season only, so that for circular area, boundary condition is $\phi = 80$ on border line of circular (Figure 8a). For rectangular area, the boundary condition is $\phi = 80$ on above and below edge of rectangular. On left and right edge is $\partial\phi/\partial x = 0$ (Figure 8b). From the well, water is withdrawn by a pump. Discharge of pumping is 1200 m^3/day for a well and also for a group of well. The soil permeability coefficient for vertical and horizontal direction is assumed equal i.e. $k_x = k_y$ = 75 cm/hour or 18 m/day. Computation is executed by solve equation (6) with finite element procedure.

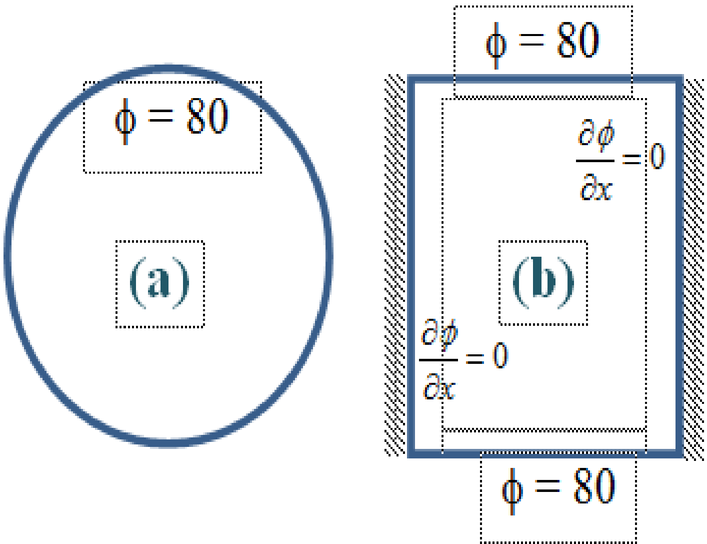

Figure 8: Boundary Condition for Computation

The depth of the well is 100 m or well is penetrated into the aquifer until to the rock layer.

RESULTS AND DISCUSSIONS

Circular Drawdown Influence

Computation and drawing result of drawdown contour map for circular drawdown influence can be seen in Figure 9 to 12.

Pumping in a well with capacity 1200 m^3/day gave drawdown map as in Figure 9. The depth of the water in the well is 48.11 m. The depth will be higher far more from the well and the depth will be constant on the border line of circular. Maximum drawdown in the well is 80 – 48.11 = 31.89 m.

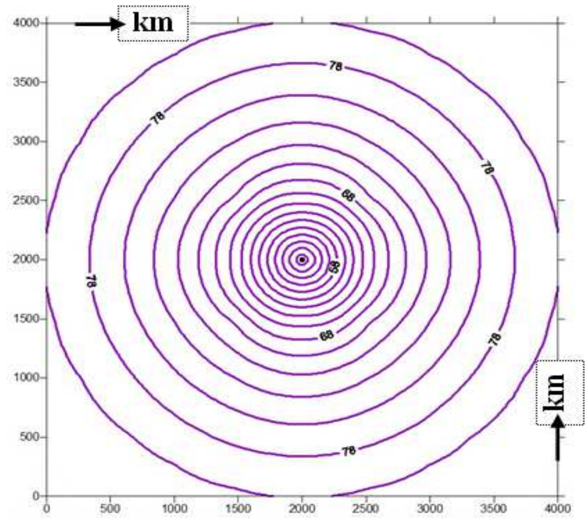

Figure 9: Circular Drawdown Influence for One Well

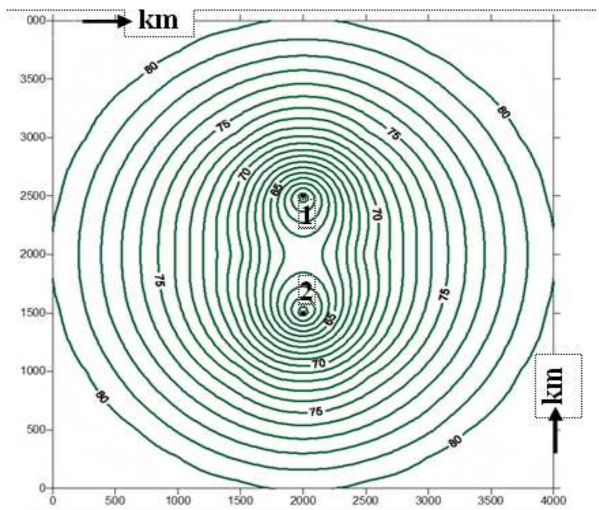

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Figure 10: Circular Drawdown Influence for Two Wells

In the circular area with two wells, capacity of pumping is 1200 m^3/day. Hence capacity of the pumping would be 600 m^3/day for each of the well. Distance of the two well is 1 km, placed in central part of the circular.

Map of drawdown that resulted from pumping with two wells can be seen in Figure 10. Water depth in each well is 60.24 m. So that maximum drawdown is 80 – 60.24 = 19.76 m. Figure 10 shows that pattern of drawdown contour map

is symmetry to the horizontal and vertical line that drawn through center point of the circular.

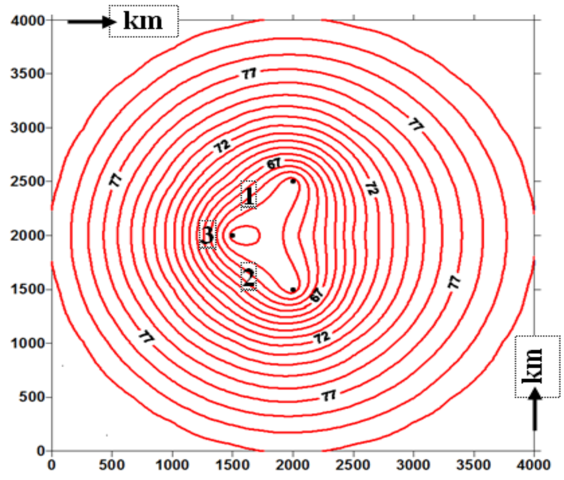

Figure 11: Circular Drawdown Influence for Three Wells

For circular area with three wells, pumping is carried out with a capacity 400 m^3/day for each of the well. The total pumping capacity for three well will be 1200 m^3/day. Result of this pumping shows the pattern of drawdown in Figure 11. Well 1 and 2 have equal water depth, i.e. 63.26 m and the depth of well 3 is 62.47 m. Hence, maximum drawdown is occurred in well 3 with value 80 – 62.47 = 17.53 m. It differ to Figure 10 that shows circular area with two wells, Figure 11 with three wells shows that pattern of drawdown contour map is only symmetry to the horizontal line that drawn through center point of the circular. To the vertical line, the drawdown contour map is asymmetry. This condition followed well placing as figured out.

For circular area with four wells, pumping is figured out with a capacity 300 m^3/day for each of the well. The total pumping capacity for four wells will be 1200 m^3/day. Result of this pumping shows the pattern of drawdown in Figure 12. Well 1, 2, 3, and 4 have equal water depth, i.e. 64.78 m. Therefore, maximum is 80 – 64.78 = 15.22 m. Since drawdown in the four wells is equal, then the drawdown contour map is symmetry to the horizontal and vertical line that drawn through center point of the circular.

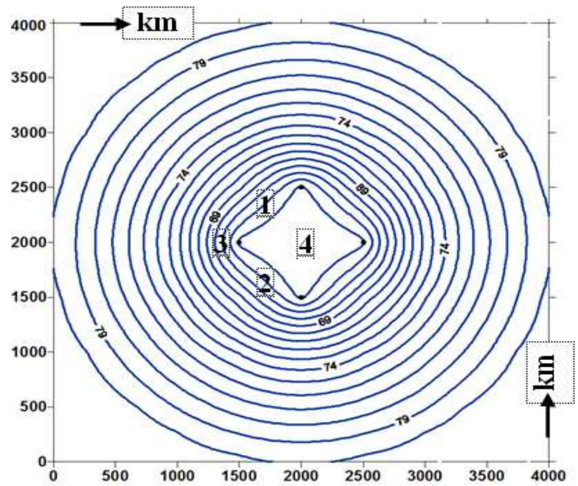

Figure 12: Circular Drawdown Influence for Four Wells

Drawdown Influence in Rectangular Area

Drawing result of drawdown contour map for drawdown influence in rectangular area can be seen in Figure 13 to 16.

Pumping capacity for the well in rectangular and circular area is the same. For area with one well is 1200 m^3/day, for two wells is 600 m^3/day for each well, for three wells is 400 m^3/day for each well, and for four wells is 300 m^3/day for each well. Drawdown in rectangular area does not differ than in circular area. Differences that shown are on the pattern of the drawdown contour map caused by shape of area where the pumping are done. Shown in both areas that contour line in the center of area tends to form pattern that nearly the same. Away from the center the contour line adjusts as the shape of area (circular or rectangular).

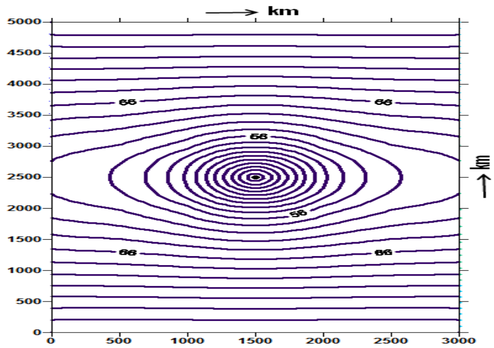

Figure 13: Drawdown Influence in Rectangular Area for One Well

In rectangular area with one well is obtained that water depth in the well is 35.48 m, so the maximum drawdown to be 44.52 m.

For rectangular area with two wells the water depth in well 1 and 2 is the same i.e. 48.56 m and the maximum drawdown is 31.44 m. For rectangular area with three well, the water depth in well 1 equal to well 2 i.e. 51.29 m. In well 3 the water depth is 49.15 m, so that the maximum drawdown is 30.85. For rectangular area with four well, the water depth in well 1 equal to well 2 i.e. 52.65 m and the water depth in well 3 equal to well 4 i.e. 51.65 m. The maximum drawdown is 28.35 m. Contrast difference is occurred on area with four wells correspond with water depth in the well. On circular area the four wells have the same depth differed than on rectangular area, the depth of well 1 equal to well 2 and the depth of well 3 equal to well 4. Higher drawdown was arisen on area with one well i.e. drawdown high 31.89 m for circular area and 44.52 m for rectangular area.

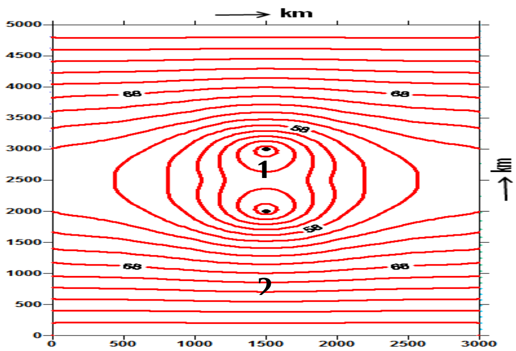

Figure 14: Drawdown Influence in Rectangular Area for Two Wells

If the deep well is exactly made, it is worried about shallow well around deep well that penetrated by people or family will be dry or less water caused by higher drawdown in deep well.

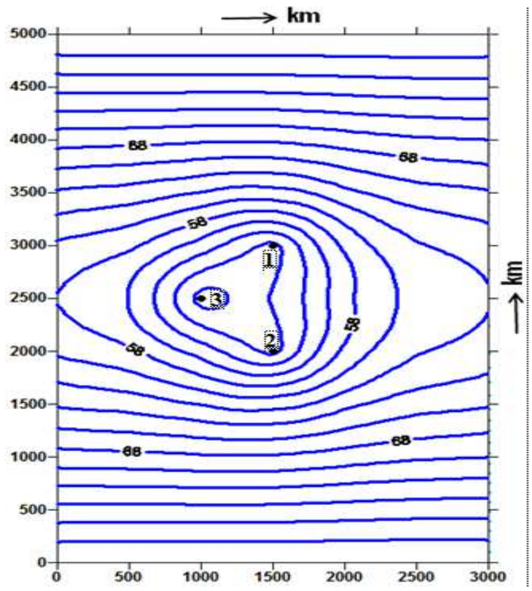

Figure 15: Drawdown Influence in Rectangular Area for Three Wells

CONCLUSIONS

The drawdown contour maps that are caused by well pumping in unconfined aquifer have been built. There are two area have been defined as drawdown influence area i.e. circular and rectangular. The well pumping from the area with one deep well resulted highest drawdown value. This condition can cause the shallow wells that penetrated by the people or family can be dry or less water. When the well more than one in the area, then the drawdown high to be goes down, as be shown in area with two, three, or four wells. Visually differences of drawdown contour maps between circular drawdown influence and rectangular drawdown influence area can be clearly seen, when we compared Figure 9 and 13, Figure 10 and 14, Figure 11 and 15, and Figure 12 and 16. The differences are affected by shape of area.

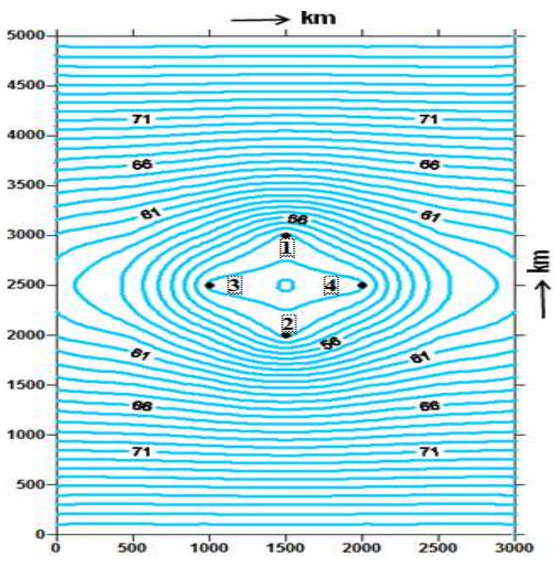

Figure 16: Drawdown Influence in Rectangular Area for Four Wells

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